

Anaxagoras and the Birth of Scientific Method

Blaisdell
Publishing
Company

A Division of Ginn and Company



Daniel E. Gershenson
Daniel A. Greenberg



History of Science





Digitized by the Internet Archive
in 2022 with funding from
Kahle/Austin Foundation

Anaxagoras
and the Birth of
Scientific Method

A BLAISDELL BOOK IN
THE HISTORY OF SCIENCE

CONSULTING EDITORS

DANIEL E. GERSHENSON
and

DANIEL A. GREENBERG

ANAXAGORAS AND THE BIRTH OF SCIENTIFIC METHOD

MERCANTILE LIBRARY
ERIE, PENNSYLVANIA

By
Daniel E. Gershenson
and
Daniel A. Greenberg

with an introduction by
Ernest Nagel



BLAISDELL PUBLISHING COMPANY
NEW YORK / TORONTO / LONDON
A DIVISION OF GINN AND COMPANY

MERCANTILE LIBRARY
ERIE, PENNSYLVANIA

FIRST EDITION, 1964

© Copyright 1964, by Blaisdell Publishing Company,
a Division of Ginn and Company.

All rights reserved.

LIBRARY OF CONGRESS

CATALOG CARD NUMBER: 63—14166

To Our Parents

Table of Contents

<i>Introduction</i> , by Ernest Nagel	ix
<i>Preface</i>	xii
<i>Chapter</i> 1. Anaxagoras' Life and Times	1
<i>Chapter</i> 2. The Constitution of Matter	5
<i>Chapter</i> 3. The Elementary Substances	14
<i>Chapter</i> 4. The Foundations of Dynamics	23
<i>Chapter</i> 5. Mind and the Theory of Perception	27
<i>Chapter</i> 6. The Creation of the World	34
<i>Chapter</i> 7. Specific Physical Theories	38
<i>Chapter</i> 8. Astronomy	47
<i>Chapter</i> 9. Earth Sciences	51
<i>Chapter</i> 10. Biology	55
<i>Epilogue</i>	58
<i>Notes</i>	59
<i>Index</i>	61

Introduction

Most natural scientists today give little serious attention to the historical development of even their own special discipline, and many of them regard the history of science as hardly more than an otiose preoccupation with erroneous views which were once current in now outdated sciences. It would indeed be difficult to justify the study of that history as indispensable for a successful career in natural science. Nevertheless, even if one discounts completely the possible value of such a study as a source of suggestions for resolving problems under present inquiry, as a convenient pedagogic approach for presenting modern scientific conceptions to beginners, or as a clue to the explanation of the character of civilizations different from our own, its potential utility to practicing scientists is still considerable.

For an analytic history of science can supply an enlightening perspective for viewing current scientific beliefs and examining them critically. It can do this by making evident some of the preconceptions that controlled scientific investigations in the past, and thereby directing attention to tacit assumptions underlying our own scientific convictions and procedures; by presenting various substantive as well as methodological notions that proved to be inadequate or mistaken when employed in earlier inquiries, and thereby enabling us to recognize more easily limitations in our own conceptions or to avoid with less difficulty similar errors; and by indicating the variety of ways in which scientific ideas are subtly transformed when their range of application is extended or otherwise modified, and thereby helping us to appreciate the flexibility of our own intellectual constructions as well as to guard ourselves against misleading

myopic interpretations of our theoretical formulations. At its best, the history of science is an enterprise which can liberate us from a provincialism in thought that is not even aware of the possibility of alternatives to the scientific conceptions currently held to be fundamental; and while its study may be of no aid in solving technical scientific problems, familiarity with it can enlarge the scientist's angle of vision.

In any event, men have long been aware that the fortunes of mankind are intimately related to its understanding of natural processes; and although the investigation of the historical growth of such understanding has acquired the status of a distinct professional discipline only recently, interest in its history is almost as old as is systematic scientific inquiry. However, the writing of an adequate analytical account of the development of scientific ideas makes large demands upon the historian. Ideally at least, he must possess not only the customary equipment of historical scholarship, as well as have the linguistic and other skills requisite for examining and evaluating the pertinent record of the past. He must also be sufficiently proficient in the relevant branches of substantive science, as well as have a mature competence in the analysis of ideas, to enable him to appreciate the technical importance and the logical interrelations of the conceptual innovations and changes upon which he is reporting. It is therefore not surprising that the outstanding contributions to the history of natural science have in the main come from students who, like Ernst Mach and Pierre Duhem, had a thorough training in some branch of science and were at the same time sensitive to the logical issues involved in scientific inquiry.

These ideal requirements for a historian of science are not commonly embodied in a single individual, particularly in areas of study such as ancient science where, partly because of the increasingly specialized character of the preparation necessary for many modern learned professions, the scholarly and linguistic skills needed for competent research in those areas are only infrequently coupled today with a comparable scientific and philosophical competence. However, the intellectual equipment of a single student can sometimes be joined to that

of another, to produce a work of significant scholarship which neither of them could perhaps achieve singlehanded.

This possibility is brilliantly illustrated by the first fruit of the collaboration between Dr. Gershenson, a classical scholar, and Dr. Greenberg, a theoretical physicist. Their combined professional training and experience obviously qualifies them to present an authoritative and penetrating analysis of the thought of Anaxagoras—although only someone who is himself a classical scholar, which I am not, is competent to assess in detail their interpretations of the fragmentary documents relating to Anaxagoras that have come down to us from antiquity, or their admittedly controversial evaluations of the extensive secondary literature on the subject. It is refreshing as well as illuminating to read an account of an ancient thinker's efforts to understand the physical world which is written, as the authors note in their Preface, "from the point of view of a scientist surveying the work of a distinguished colleague of a past age who was concerned with questions very much alive today." Their expert familiarity with the great organizing ideas of modern physics enables them to recognize and make explicit the seminal principles still being exploited that Anaxagoras employed in his investigations. (In consequence, unlike many accounts of Anaxagoras, they present his ideas not as a scarcely intelligible jumble of unsupported speculations, but rather as components in a unified theory of natural phenomena for which he believed he had reasonably good observational evidence.) On the other hand, their disciplined classical scholarship prevents them from committing the tempting fallacy of seeing in Anaxagoras' conceptions only what contemporary science regards as credible; and they indicate lucidly just how his assumptions differ from those currently accepted as valid, and why some of the former have proved to be unsatisfactory. Their book certainly testifies to the fact that collaboration between students with different but complementary professional training can produce clarifying works of historical reconstruction which, like many products of the mingling of different races and cultures, are distinguished by a creative vitality and a sound originality.

Accordingly, the discussion of Anaxagoras presented in this

book can not but fascinate the reader with a lively interest in the adventure of ideas. But the book also holds out great promise for the quality to be expected of further installments in the vast project upon which its authors are embarked to present in full the scientific thought of antiquity. May this first issue of their collaboration serve as an example not only to themselves in their further inquiries, but to other explorers of the history of science as well!

Columbia University

ERNEST NAGEL

August, 1962

Preface

Anaxagoras was the first thinker of repute who was a scientist in the sense in which we use the term today. This book is a study of his theories and methods and brings all that we know with reasonable surety about Anaxagoras and his scientific doctrines. The material is presented from the point of view of a scientist surveying the work of a distinguished colleague of a past age who was concerned with questions very much alive today. The account is necessarily incomplete and in places somewhat fragmentary. This is primarily due to the fact that Anaxagoras' writings have long been lost, so that we must rely exclusively on partial accounts and random mentions in other writers.

This book comprises the text and some of the notes of Part I of *Anaxagoras and the Birth of Physics* (Blaisdell Publishing Company, 1963). All of the background material used in its preparation will be found in the remaining notes to Part I, as well as in Parts II and III of that volume. Since this material is considerable in bulk, we have preferred to omit it entirely here, rather than present a partially documented account to the reader. We have, then, included here only the conclusions we reached in our study of Anaxagoras, while all the sources together with their interpretation are to be found in the above volume, to which the reader is referred if he wishes to know the basis on which our statements here are made.

In this book we have not studied the relationship between Anaxagoras and other thinkers who preceded him, were contemporary with him, or came after him. Mutual influences, both broad ones and ones limited to the formulation of specific theories, surely exist, but they will not be treated here. In the

present volume we have concerned ourselves only with Anaxagoras' natural philosophy, taken as a coherent system of thought capable of being described in its own right.)

We wish to thank our teachers and colleagues, as well as many students, in the Departments of Greek and Latin and of Physics in Barnard College and Columbia University, whose interest and sympathy has been a source of encouragement to us throughout. We are especially grateful to Professor Saul Lieberman of the Jewish Theological Seminary of America, whose students we have been for some three years. If there is merit in this book, much of it is due to our having learned in the course of our studies with him fundamental methods of dealing with ancient texts, as well as the basic frame of mind in which texts must be approached if antiquarianism and adumbrationism both are to be avoided. To Professor Ernest Nagel of Columbia University we are deeply indebted for his interest in our work from the beginning of our collaboration, for his support and encouragement, and for his willingness to write the Introduction to this book.

It is a pleasure to acknowledge also the aid of a number of friends who helped us throughout the year. We would like to thank Miss Christa Gussow for carefully typing and retyping the drafts of our manuscript. We owe a large debt of gratitude to Mr. Dennis Flynn for carefully reading extensive sections of the manuscript. The suggestions he made led to many changes and corrections which helped us make the presentation more readable and clear. We are also grateful to Dr. Richard Friedberg for his many helpful comments on the book. To the Inter-Library Loan Service of the Columbia University Libraries, and to the staff of the Physics Library of Columbia University, we are indebted for aiding us to locate many books; without their aid much of the material we used would have been unavailable to us. Our thanks are extended also to Mr. Joseph Keren for helping us read two articles written in Czech.

To a large extent the preparation of this book has been made possible by the generous aid we received from the Alfred P. Sloan Foundation at the very outset of our work. The encouragement that the award of this grant afforded us, and especially

the direct encouragement given us by Dr. Arnold Zurcher and Dr. Larkin Farinholt, of the Foundation, provided us with a lively incentive during the course of our work. We are grateful too to the National Science Foundation for a grant that gave us invaluable assistance through the final stages of the preparation of this book.

DANIEL E. GERSHENSON
DANIEL A. GREENBERG

New York
June, 1962

Chapter One

ANAXAGORAS' LIFE AND TIMES

The emergence of scientific inquiry as we know it today is almost impossible to trace. People have always wondered about the behavior of things around them. From earliest times human activities have been determined by the succession of night and day, winter and summer, rainy and dry seasons, growth and decay, life and death. Thoughtful men were always concerned with the nature of these phenomena and sought explanations for them.

For a long time "scientific" activity proceeded along various paths. Some people collected and organized vast amounts of empirical data, investigating all sorts of correlations between events and recording their findings in almanacs, books of augury, and astronomical tables, which were the first great scientific handbooks. Others devised means to control their surroundings, developing technologies of agriculture, manufacture, and commerce. And where they failed in their efforts to provide for the future on the basis of correlations with the past, or to control nature directly, many people tried with sacrifices, prayers, vows, magic, and ritual to move the living powers they saw behind natural occurrences, powers which appeared sometimes capricious and sometimes rational, sometimes benevolent and sometimes destructive.

All these activities led to increased knowledge, technology, and understanding, but despite this progress, that particular indefinable combination of observation, experiment, and reason which we today associate with scientific activity does not seem to have been present to any considerable extent in Western societies before the flowering of Greek civilization. Although the origins of science reach back into prehistoric times, and its "beginnings" remain—and perhaps will forever remain—undis-

covered, the emergence of natural philosophy as an experimental and theoretical pursuit in a form fundamentally the same as its present one can be said to have occurred in the Hellenic world at about the same time that the last of the prophets were preaching in Israel and the first consuls were ruling in Rome. The first natural philosopher (in the present sense of the term) whose name is known to us, whose system has been preserved, and whose fame as the founder of the new natural philosophy was celebrated throughout antiquity, was Anaxagoras.

Anaxagoras was born in Ionia, the western coastland of present-day Turkey, about the year 500 before the Christian era.¹ He was a native of the city of Clazomenae, a thriving port on the shores of the Aegean Sea. As the son of the wealthy Hegesibulus he doubtless had ample time and leisure in his early youth to pursue his studies and to learn the philosophical theories current in his day.

At the time of Anaxagoras' birth, Athens was taking its place as one of the leading cities in the world. Twice in ten years she defeated the Persians, who had embarked on punitive expeditions against her: in 490 the expedition of Darius was halted on Athenian territory at Marathon, and Athens emerged as a considerable military power; in 480 victory in the naval battle off Salamis established Athens, under the leadership of Themistocles, as the greatest maritime power in the world. In cultural matters too Athens came to be first among the Greeks. Painting, sculpture, architecture, music, drama, mathematics, logic, rhetoric, and natural philosophy all flourished within her walls.

Anaxagoras came to Athens when he was about twenty years old. He was immediately accepted into the highest circles, numbering even Themistocles among his associates. His brilliance attracted many students, the most distinguished of whom was Pericles, political leader of Athens at the acme of her greatness, from 454 to 431. Later, when Pericles' fame had spread over the world, the close relationship between teacher and student became famous too. Pericles openly acknowledged his indebted-

ness to Anaxagoras, and the latter came to be known everywhere as the instructor of Pericles.

Not only did Anaxagoras transmit his teachings orally to students who came to hear him, but he also prepared a written account of his physical theories and published it as a treatise on natural philosophy. The book soon became a standard text in Athens, and we find Socrates too turning to Anaxagoras' book to learn the laws that govern the physical universe. Anaxagoras' teachings were so well known that many of them were inserted into the dialogues of plays, either in a serious vein in tragedy, or as material for lampoons in comedy.

In addition to his intellectual achievements Anaxagoras possessed personal character traits which set him apart from his fellow men, and made him the archetype of the popular image of an "up-in-the-air" intellectual. He completely renounced the ordinary pleasures and duties of everyday life and withdrew entirely from political affairs and from personal involvements. Through neglect and inattention he allowed his ample inheritance to waste away. Instead he gave himself over to his studies and immersed himself in his scientific investigations. He would often say that the sole purpose of life is to observe and ponder natural phenomena and to attempt to explain them rationally. According to him, a life devoted to theoretical investigations—a life of retirement from practical affairs, of complete preoccupation with contemplating the heavens and with viewing the grand design of the universe—was the truly happy life, though to most people it seemed just the opposite.

In fact Anaxagoras held that the experiences of day-to-day life have no intrinsic value at all, good or bad; for he believed that the significance of every situation depends entirely on the way one looks at it. [This belief led him to conclude that observation can furnish a true picture of physical reality only if properly analyzed. It also revealed a detachment of character reflected in the story later told of him that he received the report of his son's death calmly and without emotion, with the simple statement that he had known his son was mortal from the day of his birth.

Thus the image Anaxagoras presented was that of a philosopher totally indifferent to matters of the flesh and consumed with a zeal for knowledge and for the pursuit of truth. Such an image easily lent itself in later ages to all sorts of legends and tales and caused him to be cited often as an example in moralistic sermons for and against abstract philosophy.

Anaxagoras lived at Athens for about thirty years. It is not possible to trace his steps during the years following his departure from Athens. We find him last in the city of Lampsacus on the Asiatic coast of the Dardanelles, where he died when he was about seventy years old. The citizens of Lampsacus, eager to pay tribute to greatness in their midst, gave him a public funeral and continued to honor his memory for over one hundred years after his death.

Anaxagoras' life spanned the golden age of Athens. He was the first natural philosopher of note to reside in Athens, the only one to remain there for any considerable length of time during its most flourishing period. His physical theories exerted a profound influence on scientific thinking there, and this influence still prevailed a century after his death.

Chapter Two

THE CONSTITUTION OF MATTER

The basic question which must be answered by any physical theory is: what is the nature of matter? Contained in this fundamental query are many other questions: What are the fundamental properties of the substances that make up the world around us? Is matter discrete or is it continuous? Must it all be perceptible to touch? What kind of changes does it undergo, and by what laws are these changes governed? What keeps objects together, and endows them with their properties? These questions faced Anaxagoras as they have faced physicists throughout history. The answers he gave and the methods he used to reach them allow us to appreciate the insight he achieved into the nature of matter.

In investigating these questions Anaxagoras employed two important and distinct methods, each of which was undergoing separate development in his day. The first method consisted of careful and meticulous observation, by means of direct sense perception, of the phenomena which took place around him. Large numbers of events had to be studied and a multitude of processes had to be followed in detail. Nothing at all could be omitted since at this nascent stage of science it was almost impossible to distinguish something important from something trivial, or something complex from something simple. On every new frontier this is so: within the domain which is as yet unexplored all avenues must be followed until there appears some pattern which serves to differentiate basic features from irrelevant or secondary ones. For Anaxagoras the new frontier was the whole of the physical world, and there was no part of it which escaped his careful attention; the stars at night and the sun by day, earthquakes and cloudbursts, the organic and the inorganic all were studied, all noted, and all somehow fitted into his emerging system. Beyond the scope of passive observa-

tion lay things which could be determined only by active interference with the natural course of events, so that the results of experimentation also found a place among his observations. True, the data he accumulated "passively" outnumbered that which he gathered through experiments, but this was only because the variety offered by nature itself was so great, so novel, and so little understood that it alone provided ample challenge to the investigator.

The second method Anaxagoras adopted in constructing his physical theories was the newly formulated method of logical analysis. Logic has always been used by people to organize their thoughts into patterns involving generally accepted axioms as well as modes of deduction which link one thing with another as antecedent and consequent. The rules have differed, and there has never been a universal consensus on just precisely what a system of thought must be in order to be "rational." Nevertheless it seems that there evolved, at least in the West, a fairly uniform concept of reason intuitively understood and used in everyday life. This intuitive concept first underwent careful review and development at the hands of Greek thinkers around the time of Anaxagoras. What they began to do was to lay down rules in an explicit, formal manner as rules of logical thought. There followed a period of development that culminated with Aristotle's famed treatise on formal logic, which served to summarize and extend two centuries of painstakingly wrought advances, some of which can be seen being forged in the probing studies of logic found in Plato's dialogues. Anaxagoras lived at a time when only the first strides had been taken, but he made full use of the results available to him.

These two methods were the basic tools used by Anaxagoras to study the nature of matter, and the nature of the physical universe as a whole. Indeed, the most important feature of Anaxagoras' theory is the simple fact that he employed both methods, that he insisted that all observations be fitted into a logical framework. It was he who first demanded that observation *and* logic join hands in natural philosophy; that neither take precedence over the other; and that where they seem to

conflict they must be conjoined, harmonized, and even compromised, without either of them ever being abandoned. We will see many instances of Anaxagoras' attempts to achieve this harmony; but the real importance of these attempts is that they were made at all and that Anaxagoras never allowed his physics to fall wholly into the realm of abstraction and fantasy, or to be bound entirely by the appearances perceived by the senses.

The data offered by the senses convinced Anaxagoras that the world around him was infinitely varied and that everything in it took part in never-ending processes of physical change. There seemed to be no limit to the variety of objects that *can* exist and no limit to the variety of those that do actually exist in the universe. When a red object fades, it assumes successive shades of red and pink until all color has vanished; when a lump of sugar dissolves it undergoes continuous diminution until it finally disappears; when a piece of iron rusts away it passes through all the stages that lie between metallic hardness and powdery softness. The intermediate states through which any object passes in the course of change are innumerable, and any one of these states can be realized if the process is somehow stopped short.

In the course of time *all* perceptible objects undergo changes and transformations, which go on without end. Consider for example a burning log. Part of the log rises as smoke into the clouds; thence rain descends into bodies of water, in which salts and earthy precipitates form; from earth, mists rise into clouds, and out of earth there are formed stones too, which give off sparks that kindle flames that can again consume a log. Part of the log remains in the form of ashes, which crumble into earth and nourish the plants that grow from it; again, these plants nourish animals, whose fate it is to return once more to earth. If we chose to follow the burning log in detail through all the transformations of all its parts, it almost seems—as it seemed to Anaxagoras—that it would eventually pass through every state of every substance in the world; that it would, in short, encompass the sum total of all things that exist.

For Anaxagoras, then, infinite variety and never-ending change were everywhere characteristic of matter, and he set about to explain them in terms of the stable categories of scientific thought. In his eyes, continual variation and transmutation were omnipresent motifs in nature, and it was these that had to be rendered comprehensible through a set of discrete logical statements.

The fundamental law of logic which had gained widespread acceptance in Anaxagoras' time was the Law of Contradiction, which states that a proposition and its negation cannot be simultaneously valid, i.e. that it is impossible both to be and not be something at the same time. This law has particularly interesting consequences when applied to the statement that some specific thing actually exists. For if we say of something that it really exists, that it really is, that existing can really and truly be predicated of it, and that existence is inherent in it, we can not say of the same thing that it does not exist; so that, inasmuch as a fundamental, inherent property is by definition permanently attached to the object it modifies, anything that really and inherently exists must exist for all time. The Law of Contradiction applied to the basic property of existence results in a kind of Law of Conservation of Existing Things, frequently repeated in Anaxagoras' time, which states that something *real* can not come out of nothing, and that anything that really exists can not have been nonexistent in the past or be nonexistent in the future—that it can not ever not have been and can not ever disappear.

Of course, the Law of Conservation of Existing Things only becomes relevant in natural philosophy when it is decided how the law will be applied, i.e. when it is stated clearly just what it is that should be assumed really to exist. Different assumptions correspond to different ways of looking at the world. Sometimes these different assumptions may lead to different physical theories which give equally valid results; and sometimes they may lead to physical theories which yield incorrect results, in which case they must ultimately be abandoned. Anaxagoras had to make at the very outset a fundamental choice of what things he would take to be real, permanently stable, and eternally conserved in this world of continual change.

To most people the only things that are real are those objects they can touch, feel, and handle. For them the things that count are things that directly impinge on their senses, and not abstract ideas or concepts. What exists in their view is *matter*, having weight, size, texture, color, taste, smell, temperature, and other such properties. Matter can not be conjured up, nor can any magic make it disappear; even when things wear away, they only turn into dust, and dust is no less matter than the original object was. Matter is stable; a mountain or a table is not here today and gone tomorrow. For most people, then, the Law of Conservation of Existing Things becomes a Law of Conservation of Matter, according to which different kinds of matter are eternal and suffer no diminution or addition. Anaxagoras accepted the view that matter is eternally conserved, though as we shall see he did not believe that it is the only thing which really exists.

On the basis of considerations to be discussed in detail in the next chapter, Anaxagoras chose organic substances having a certain set of inherent properties as the fundamental, basically real kinds of matter in his theory. These substances were what we today would call tissues, things like flesh, bone, blood, marrow, leafy matter, bark, etc. A full list was certainly never made, perhaps because the possibility of new discoveries in the field of biology was always felt to be present. Thus the number of different kinds of basic substance remained indeterminate and might even have been thought to be infinite. As for the basic properties belonging to these organic substances, these were taken to be one of each of the contrasting absolute qualities, such as (absolute) hotness and (absolute) cold. The number of these pairs of contrasting qualities was probably also not specified, and may well have been left open. In Anaxagoras' theory, then, there existed a number of elementary kinds of matter to which basic, discrete properties were permanently united. The amount of each kind of matter, together with all the properties belonging to it, was fixed once for all, and could not change through any interaction or under any circumstances.

It is noteworthy that in forming his picture of physical reality Anaxagoras took different kinds of matter *and* their different properties to be basically real and immutable. In this way he introduced three separate conservation laws into his

physics: (1) a restricted law saying that the amount of each specifically characterized kind of matter is conserved (according to which, for example, the total amount of *hot, light, and sweet flesh* is conserved, the total amount of *cold, light, and sweet flesh* is separately conserved, and similarly for every kind of matter with every specific set of properties); (2) a broader law, following from (1), saying that the total amount of any kind of matter, regardless of qualities, is conserved (e.g. the total amount of all *flesh* is conserved); (3) a law parallel to (2), derived in a similar manner from (1), saying that the total amount of any particular absolute quality, regardless of the substances to which it is attached, always remains the same (e.g. the total amount of all different kinds of matter to which the property of *being cold* belongs always remains the same). In addition, of course, the general Law of Conservation of Matter, saying that the total amount of *all matter* taken together is conserved, was also true in Anaxagoras' theory, as it was taken to be true quite generally before him.

The fact that the elementary substances and qualities taken to be real and eternal by Anaxagoras were chosen from among the common everyday substances and qualities which we perceive all around us gives some measure of the degree to which Anaxagoras was committed to the reality of perceived phenomena, even while insisting on the role of logic in the formulation of his theory. To the question, "What really exists?" Anaxagoras replied that *things of the kind we perceive to be real* really exist. Thus Anaxagoras introduced into natural philosophy at the very outset a reluctance to depart from the generally familiar categories of macroscopic phenomena. This reluctance was to remain at the heart of physics for some twenty-five hundred years and to resist tenaciously all efforts to displace it. Anaxagoras would have nothing to do with a system which derives the perceived world from a set of primary entities which are inherently different in nature from those used to describe perceived phenomena. Until the twentieth century, succeeding generations of physicists (with some notable exceptions) for the most part concurred.

We see then that certain kinds of specifically characterized substances served as basic elements in Anaxagoras' picture of reality. In Anaxagoras' eyes however another element was no less real than these eternally immutable material components of the universe, and this element was *physical change*. This too had to be accounted for in a reasonable way within the theory.

Because the material components of reality could themselves undergo no change, the only kind of change Anaxagoras could allow was change resulting from the displacement and rearrangement of these components. Qualitative change simply could not take place in the theory, since the basic qualities were permanent; for once Anaxagoras had admitted the reality of the basic properties of matter, these properties had to remain unchanging and immutably linked to matter. The only way left open to account for observed physical change was through rearrangement of the stable components of which the world was assumed to be composed.

Indeed, a glance around us shows that change of position is one of the most common kinds of change: a room changes its appearance when furnishings are shifted about; a house changes into a heap of rubble when its parts crumble to the ground; a city changes when wood and stone are brought from quarries and forests and made into buildings. Change of position, so familiar in everyday life, provided Anaxagoras with a way of explaining all physical change.

With Anaxagoras, then, the conviction that observed transformations from one state to another are real and not illusory entered physical science at the beginning of its development, side by side with the belief that the substance of the material objects undergoing change is itself permanent and immutable. The apparent contradiction between these two fundamental positions made it necessary to assume that what accounts for *all* change is change of position with time. This meant that the one property of matter which might alter from one moment to the next is the position it occupies in space. The position of an object is not, then, one of the object's inherently real properties; there is no Law of Conservation of Place. Instead,

Anaxagoras took it to be perfectly possible for an object to move from one place to another as time flows on, and he believed that this motion could account for all the different kinds of change we see around us.

We are now in a position to understand the boldest step taken by Anaxagoras in formulating his theory concerning the constitution of matter. We have seen that Anaxagoras did not consider that he had only to account for change in a general way, but felt that he had to account specifically for the apparent emergence of an infinite variety of objects from any given object as time goes on, as well as for the apparent ability of an object to pass through the continuum of qualities which lies between the discrete absolute extremes of quality. The only way however that an infinite variety of stable entities can exist in a finite object is for the entities to be *infinitesimal in size*, because an infinite number of entities can be contained in a finite volume only if they are infinitely small. Anaxagoras realized that this is so and was thus led to postulate explicitly that the basic units of matter—the fundamental building blocks out of which all objects are made—are infinitesimal in size.

Anaxagoras' concept of infinitesimals was carefully conceived and worked out. Anaxagoras knew, as was widely known in his time, that an infinite number of *points* could never make up an object of finite size; for a point has absolutely no extension (by definition), so that no finite number of points—and, by induction, no infinite number of points—can have extension either. On the other hand Anaxagoras also knew, together with his contemporaries, that an infinite number of objects each of which is finite in size must occupy a volume which is infinitely large. It was therefore clear that the size of the basic units of matter must be smaller than any finite size, but larger than the size of a point, i.e. that the basic units must be of infinitesimal extension, if an infinite number of them were to enter into the composition of each and every finite object.

The entities Anaxagoras called infinitely small were infinitesimal in precisely the sense in which the word has been used

since the seventeenth century; they were magnitudes whose measure is larger than zero but smaller than any arbitrarily small number. Anaxagoras was to the best of our knowledge the first to introduce infinitesimals into a physical theory. It might be added that the difficulties which he and his successors encountered when using these new quantities were in no small measure responsible for the complete abandonment of infinitesimals in science and in mathematics for some two thousand years after his time.

Anaxagoras' theory was thus basically a molecular theory of matter. It resembled molecular theories of later ages in that it pictured matter made up of stable particles having the same properties as matter in bulk; but it differed from all other such theories in the very important respect that the molecules were infinitely small and hence able to constitute a smooth continuum. This one big difference made it a simple matter for Anaxagoras to conceive that any object had in it at least some molecules of every substance possessing every quality; and that an object assumed every intermediate quality between the extremes as the proportion of molecules possessing each of the discrete extreme qualities varied continuously.

In the next chapter we shall discuss Anaxagoras' specification of the elementary substances in his theory. But the specific choice of these substances was not as fundamental to his picture of physical reality as the conviction that among the basic elements of reality are eternally conserved kinds of matter, together with qualities, of the type we observe all the time, and changes and transformations of the type we perceive all around us. If we add to this his belief, based again on observation, that objects can exist in an infinite variety of states and that out of any object the entire infinite range of existing things eventually emerges, we arrive directly at his conclusion that physical reality is built out of an infinite number of molecules of infinitesimal size, none of them subject to change, but all of them free to move about from one place to another. This then was the starting point of Anaxagoras' physics.

Chapter Three

THE ELEMENTARY SUBSTANCES

The problem of identifying elementary substances, and of distinguishing them from compounds which can be broken down into component parts having properties different from those of the original compound, is a problem that did not proceed smoothly towards solution until the nineteenth century. In order to differentiate between elements and compounds careful and precise observations must be made. In particular it must be determined with certainty that a substance which is taken to be elementary can not be decomposed, or undergo any process which yields different substances. The fact is that over the years various kinds of matter have been considered elementary, since the elementarity of a substance depends on the experimental conditions with reference to which elementarity is defined. For example, when methods of decomposition are used which can break only weak bonds of the kind which link macromolecules in biological structures, organic molecules appear to be the "elementary" components of all living things. When chemical interactions are employed in which higher energies are available to break the stronger bonds tying together organic molecules, atoms appear to be the "elementary" components out of which all things are formed. At higher energies, atoms decompose into electrons and nuclei; and at still higher energies, the nuclei in turn break up into components even more elementary. To a large degree, then, the distinction between what is simple and what is complex depends on the range of energy employed in the experiments being performed.

As long as sufficiently accurate measuring equipment had not been developed, and as long as energies greater than those attainable from fire or from strongly interacting chemicals had

not been made available, the experimental scientist could at best hope to find the "elementary" building blocks of biology and chemistry, organic molecules or atoms. Under these conditions, the experimentalist could never obtain conclusive results because of the impurities almost always present in his substances, impurities which continually came to view with each new purification, and which could rarely be said with confidence not to be the decomposition products of the substance at hand. Thus before the nineteenth century the *theoretical* physicist, always eager to probe in his theories to the very foundations of physical reality, was forced to establish the distinction between elementary and composite substances in his theory not on the basis of clear-cut results arrived at through experimentation, but on the basis of other criteria. Anaxagoras chose life as the criterion of elementarity.

The distinction between the living and the nonliving has always been obvious, for it is evident that there are things in the world which are alive, and other things which are not. The reason for this distinction is far from clear; nor has there ever been general agreement concerning the real basis for the distinction, i.e. concerning what it is precisely that characterizes life, and what functions are peculiar to living organisms. The answers to these questions have been subjects of inquiry and debate from earliest times. On the other hand, the fact that the distinction exists has never been challenged, and every attempt to understand the physical universe has had to come to grips with this fact.

The prevalent view has taken the matter in the universe to be inherently devoid of life. In this view, organic substances are particular structured combinations of the inorganic; and living organisms are specially structured combinations of organic substances which are capable of performing the life functions either by virtue of their structure, or by virtue of some "spirit of life" within them. According to this view, then, two processes are necessary to fashion a living organism out of nonliving matter: the first a process of organization, and the second either another process of organization or a process of animation by some external breath of life.

Anaxagoras did not concur with the prevalent view. His theory did not require two separate steps to produce life out of nonliving matter. We have seen that Anaxagoras took full account of the observed fact that no substance is pure and of the further fact that in his day no substance could be verified experimentally to be elementary, in that his theory took all perceptible objects to be compounds containing particles of all other substances. Anaxagoras was therefore free to assume any substance to be elementary, and he chose as elementary all the different tissues of living organisms. In his eyes, then, *life* was the underlying feature of the physical universe; and one of the inherent eternal properties of all matter, animate or inanimate, was the organic nature of its basic constituents.

The emergence of living organisms out of nonliving matter thus needed but one act of organization, according to Anaxagoras. Since the basic particles were already organic, only a single operation was required in order for the life functions to become manifest. In the theory, when the elementary tissue-molecules are put together in the right way, the resulting object lives; otherwise the matter is inert, able to give rise to life, but not manifesting the characteristics of life as long as it remains in a state of disorganization. For example, a kernel of grain can live and grow as long as its component parts are ordered properly. Once it is ground in a mill, however, its specific structure is destroyed, and its randomly strewn parts present the appearance of inanimate flour. *Life*, then, is inherent in all things, but the *life processes* can only come to view when the elements are suitably arranged.

Inorganic matter is a mixture of organic molecules which does not display the articulated structure characteristic of living organisms. The only feature which distinguishes different kinds of inorganic matter is the definite proportion which holds between the various types of organic molecules contained in them. We do not know how Anaxagoras specified the exact proportions of all the different organic substances in, say, earth or water, or in any other inorganic substance; or whether any such precise specifications were made by him at all. Nor do we know whether he conceived inorganic substances to be com-

posed of inorganic molecules, i.e. whether he conceived discrete, infinitesimal, inorganic molecules, every one compounded of a particular number of each of the elementary organic molecules, to be the building blocks of inorganic matter; or whether he held that inorganic matter is simply a homogeneous mixture of organic molecules, i.e. a smooth, uniform blend of organic molecules combined in the proportion appropriate to the type of inorganic matter at hand. In fact these two pictures of the structure of inorganic matter would have been entirely equivalent for Anaxagoras. The first picture would correspond, for example, to the theory that earth is made of infinitesimal molecules of earth, each one a stable unit formed of a number of organic molecules combined in a certain proportion. In this case the organic components would first be bound into molecules, which would then form the substance in mass if an infinite number of them were brought together. The second picture would correspond to the theory that earth is made up of organic molecules mixed together uniformly in the right proportions to yield earth. In this case every piece of earth would have the same nature, because the mixture is uniform; even an infinitesimal piece of earth would be earth, because it contains the proportion of organic molecules that yields earth. In both pictures any amount of a given inorganic substance—even an infinitesimal amount—has exactly the same composition as the substance in mass. Since infinitesimal quantities of matter can never be observed, the difference between the two pictures is one of taste; it depends on whether you prefer to view inorganic matter as being composed of infinitesimal molecules which are tiny bound organic complexes, or whether you prefer to picture it as an amalgam in which no complex sub-unit has permanence. Hence, to postulate the existence of discrete, infinitesimal, inorganic molecules adds nothing new to the theory; still we can not be sure that Anaxagoras did not speak of such entities, if only because it would have enabled him to picture every substance without exception, inorganic as well as organic, as being a separate molecular species.

At any rate, the basic building blocks of *all* kinds of matter were conceived to be organic molecules of infinitesimal size.

Since something infinitely small can never be observed directly, and since it was impossible to determine experimentally which kinds of substances are elementary, it becomes strikingly evident that theoretical considerations alone led Anaxagoras to choose one type of matter, the organic, to be elementary, and the rest to be compound. That this choice led to a simple, more economical explanation of the difference between the living and the nonliving is testimony that Anaxagoras appreciated the fundamentally aesthetic principles of simplicity and economy in science.

According to Anaxagoras, the macroscopic bodies we see around us are formed through the conjunction of infinitesimal molecules. Any object of finite size, no matter how small, contains therefore an *infinite number of molecules*. In the case of organic substances, the majority of these molecules are molecules of the substance of which the object appears to be made. In the case of inorganic substances, the appearance of the object is determined by the proportion of different molecules within it. Homogeneously mixed into all objects however are infinitesimal pieces of every one of the infinite variety of substances which exist; so that even though an object appears to be made of one particular kind of matter, it contains within it all kinds of matter, and all kinds of matter can eventually emerge from it. Furthermore, since the pieces of foreign matter are uniformly mixed in with the predominating kinds of matter, any subdivision of the object has the same composition as any other subdivision and also contains something of everything.

Anaxagoras' picture of the composition of macroscopic bodies enabled him to account for the details of physical change. In Anaxagoras' theory, transformations can occur in a number of ways, all of which are processes of dissociation and recombination involving spatial rearrangement of the molecules. For example, some of the molecules of one of the substances which lies hidden from view within an object may be separated out of the object and be brought together

elsewhere to form a new object, having the appearance of the substance extracted. This occurs when a plant grows out of the earth—molecules of plant matter are extracted from the earth—or when salt precipitates out of a solution. The residual object which is left behind may still appear relatively unchanged (as do the earth and the solvent, in the examples cited above); or it may take on a different appearance if enough molecules have been extracted to alter significantly the composition of the body (as when digested food takes on the aspect of waste products after most of the nutritive tissue-molecules have been extracted for the body's use). Another mechanism of change is the addition of a small or large number of molecules of some particular kind to an object. In this case the previously prevailing balance is upset, and the object takes on a new appearance determined by the new proportion of molecular components (as when wine is mixed with water). Alternatively, pieces of composite substances can dissociate, as Anaxagoras may have envisioned happening in cases of nutrition and growth (where he may have imagined that the decomposition of inorganic substances into their organic components also took place).

It now becomes clear why Anaxagoras was led to ascribe discrete absolute qualities to his elementary molecules, rather than endowing them with the full continuous range of observed qualities. Suppose, for example, Anaxagoras had included in his theory particles having every degree of hotness. He would then have had to say that an object which is at room temperature contains in it a majority of particles having room temperature as their permanent, immutable degree of hotness. In order to explain how such an object becomes slightly cooler or warmer when placed before a window, or when moved a bit nearer to the fire, he would then have had to say that a considerable amount of matter is exchanged with the surroundings, such that most of the particles which are at room temperature leave the body, while other particles of the same substances as those that left, having slightly lower or higher temperature, enter the body from the adjacent surroundings in numbers large enough to form a new majority and so give the body its new temperature.

Such great flows of matter obviously do not occur when slight, gradual qualitative changes take place. It is therefore clear that the qualitative continuum we observe can not correspond to a qualitative continuum in the elementary particles.

Anaxagoras however could give a much simpler explanation of qualitative change, since the infinitesimal size of the molecules in his theory enabled him to construct a continuum out of discrete quantities. By assuming, for example, that only two degrees of temperature exist, absolute cold and absolute hotness, and that one or the other was an immutable property of every molecule, Anaxagoras could account for an object having any intermediate temperature lying in the continuum between the two absolute endpoints by assuming that the object contained an appropriate ratio of molecules of each of the two extreme temperatures. The fact that the molecules were infinitesimal in size made it possible for the qualitative continuum to be completely smooth, with no gaps or jumps. Furthermore, transitions which take place from one state to another differing only a little from the original one could now be accounted for in a reasonable manner: a *small* transfer of matter to or from an object would suffice to alter the ratio of molecules having the two qualitative extremes, and so to alter the value of the observed quality to a neighboring value. The number of molecules transferred in any process of qualitative change would thus be proportional to the extent of the change. In particular, small or gradual changes could occur with no perceptible transfer of matter to and from the surroundings—in complete agreement with observation!

In Anaxagoras' theory, then, each of the basic molecules possessed a set of basic, discrete, absolute qualities. Each one of these qualities represented one of the contrasting extremes bounding the continuum which that quality is observed to span.

There are a number of consequences from this theory of matter which appear at first sight to be paradoxical. In the first place, since Anaxagoras considered only the extremes of the qualitative continuum to exist in the real sense of the word, no predicate could truly be applied to any actual object in the

world; the statement that a specific property really belonged to any given object could never be valid. This is because any actual thing, according to Anaxagoras, contains within it, as part of the mixture which makes it up, at least *some* matter which has each of the contrasting extreme qualities, and a property which manifested itself at any particular moment could disappear from view as the result of ever so slight a mechanical displacement of some of the body's component parts. The only predicates in the theory that could ever be imagined to be valid of a body are the contrasting extremes, since only these really exist in the theory. But since every body contains some of each of the extremes, neither one of the extremes could be legitimately predicated of the body as a whole; nor could *both* extremes be predicated of the body, since in that case contrasting predicates would apply to the same body simultaneously, in obvious violation of the Law of Contradiction.

The only exception might be thought to occur in the case of a pure body made up either entirely of one kind of substance, or of substances having only one of the two absolute extreme qualities. Here however we come face to face with a second interesting consequence of Anaxagoras' theory, that *no perceptible substance or quality is or can ever be pure*. That none is pure we have already seen, since every object in the world—as Anaxagoras saw it—actually contains something of everything. That none *can ever* be pure is guaranteed by the infinitesimal size of the molecules, because any process of purification involves the transfer of finite pieces of matter (though they may be very small), and these always contain at least *some* infinitesimal molecules of everything else.

A third consequence of the theory is that all objects of finite size contain the same number of molecules, an infinite number. Thus, though there is more water in a pail than in a thimble, or, to take another example in a somewhat different vein, more water than flesh in a pail of water, there are the same number of molecules present in both. This, of course, is just another of the long list of paradoxes of the infinite which led natural philosophers soon after Anaxagoras to abandon for all practical purposes all infinite quantities, whether infinitely large or in-

finitely small, at least in so far as their specific theories were concerned. Even Anaxagoras did not suggest that the range of variation of any of the observed qualities is infinitely extended. Even he assigned definite limits to this range, postulating the existence of extremes of qualities defined by the pairs of contrasting absolute qualities. Perhaps even he was not prepared to admit into his theory infinite quantities where he did not feel they were required by observation and logical analysis.

Chapter Four

THE FOUNDATIONS OF DYNAMICS

Anaxagoras was the first to realize that it is not enough to determine the nature of the material components that make up the universe, but that it is necessary also to provide an explanation for the motion and change that matter undergoes. He did not content himself with saying that matter behaves the way it does because it is its nature to behave that way, but he sought a single unifying principle from which could be derived in all its detail the behavior of each and every part of the universe for all time.

The desire to find a single, all-embracing, dynamical principle was bequeathed by Anaxagoras to all physicists who came after him. What was involved was the rejection in principle of a system of theoretical physics based on a multiplicity of laws, each governing particular kinds of matter, or particular types of event, or particular eras of time. Anaxagoras clearly indicated that the goal of dynamics is the discovery of *one* law, *one* force, which governs all the many phenomena of physical reality.

Anaxagoras was looking for something which has the following characteristics: (1) It must be one, not many. (2) It must be responsible for all motion and change of state that takes place in the world and must suffice to explain and give direction to all physical change. (3) It must be thoroughly logical and rational, and devoid of any mythological, capricious, or even theological character. (4) It must account for the marvelous order visible in the universe and for the harmonious functioning of all parts of the physical world. Postulating that such an entity really exists, Anaxagoras gave it a symbolic name, the name ordinarily given to the single agent which fulfills all these functions in living beings—"Reason," or "Mind."²

In applying this name to a cosmic entity Anaxagoras was

making use of a method frequently resorted to by scientists, and fundamental in human thought: the method of analogy. By analogy, one isolated phenomenon can be connected to and explained through another with which it has features in common; in this way Anaxagoras accounted for plant behavior in terms of animal behavior,³ for lightning flashes in terms of ordinary fire,⁴ and for the sun in terms of glowing red-hot ore.⁵ By analogy too, a universal phenomenon can be related to and rendered comprehensible through a particular one; in this way Anaxagoras accounted for the creation of the world in terms of rotational fluid motion,⁶ and for its continued functioning in terms of the factor which maintains the functioning of living things. By such analogy Anaxagoras introduced into his system the conception of a cosmic Mind as that which accounts for the ordered, rational behavior of physical reality, and he pictured the behavior both of the individual and of the universe as manifesting the presence of the same dynamical agent, Mind.

The mind of man is generally credited with displaying many of the characteristics of Anaxagoras' cosmic Mind. Mind in man seems to be characterized by rational thought. It enables man to control his environment and to impose some order on the things around him. The mind allows man to initiate processes of motion and change, and endows him with the capacity to govern much of what is around him. Anaxagoras also identified with the mind of living organisms all their manifestations of structure, even those which we today do not normally associate with the mind. Thus, for example, the physiological function of digestion by which food is ingested and from it are extracted those substances which make up the tissues of the body was for Anaxagoras a function of the mind. Similarly, the reflex actions and instincts of plants and animals, as well as their ability to grow and thrive on nourishment provided by the surroundings, indicated to Anaxagoras that they too possess minds.

The analogy between the mind of individuals and the cosmic Mind was more than a casual analogy for Anaxagoras. In his eyes the highly specific structure and behavior of individual

plants and animals indicated that each of them is permeated by its own individual mind, which allows it to move, and to change, and to control its surroundings. In just the same way, the order and structure of the universe as a whole indicated to him the omnipresence of a cosmic Mind which can move and control its sphere of influence—the entire universe—in a rational way. The cosmic Mind pervades all of nature just as the mind of each individual living being pervades its entire body.

The hypothesis of a cosmic Mind was the perfect complement to Anaxagoras' theory of the composition of matter. For we have seen above that at the heart of his theory of the nature of matter lay *life*, which was basically linked to all material things. Here, we find at the basis of his theory of motion and change the dynamic, rational, and ordered aspect of life, namely, Mind. Thus the entire universe took on the aspect of an infinitely great, perfectly structured organism, constructed out of the same basic matter as living organisms, and governed by the ruling power of Mind.⁷

Mind embodies the idea of natural law. It does not possess caprice or will or the ability to make decisions. Instead, it was meant to be the source of all changes in the universe, as well as the source of all static order. Anaxagoras' theory of a cosmic Mind was the expression of the conviction that all of nature behaves according to strict law; that there is no such thing as disorganized behavior; that nature knows no chaos or randomness; that, in short, law and order characterize all the matter in the universe wherever it is found. Thus, according to Anaxagoras, Mind is in all things and controls all things, since everything is ruled by reason.

Mind was real for Anaxagoras, as real as the order and change for which it was responsible. In fact, Anaxagoras' assumption that Mind exists as a real entity summed up his belief that the order and change we perceive around us are not illusory, but are actual elements of reality. The law governing the motion of matter was for Anaxagoras an unchanging, eternal law, because Mind, which embodied this law, was real and hence immutable, and completely free from change or alteration. In essence then two basically different kinds of things truly existed

as far as Anaxagoras was concerned: infinitely varied matter with its characteristic properties; and Mind, the single dynamical agent responsible for everything that happens.

One would naturally expect that a theory which includes a single comprehensive factor to account for the behavior of all things in the universe would also show *how* the workings of Mind are manifested in detail. In introducing Mind Anaxagoras was declaring his belief that there does not exist more than one basic explanation for physical phenomena, thus leading people to hope for an explicit formulation of the basic principle or law governing all of nature, or at least for a general description of the law governing the behavior of Mind, from which all phenomena could be deduced as particular cases. Unfortunately Anaxagoras did not provide such a unified law, and his successors took him sorely to task for this major flaw in his theory (though they in turn were hardly more successful than anyone has been in their search for such a law). In his discussion of specific phenomena Anaxagoras resorted to purely mechanistic explanations based on a variety of mechanical and biological laws of the kind used by other natural philosophers of his day.

It is difficult to suppress a feeling of disappointment in a theory which announces that a unified principle exists, and then fails to set it forth. Nevertheless Anaxagoras deserved the praise lavished on him in his own time and ever after for being the first to look for such a unifying principle and to make its existence a cornerstone of his theory.

Chapter Five

MIND AND THE THEORY OF PERCEPTION

For Anaxagoras, Mind was very real. Its effects could be seen in living beings as well as in the universe, and every process of physical change could be ascribed to its presence. What kind of thing was this Mind?

In living organisms the mind can not be seen. It is not an organ nor a particular kind of tissue; but as the factor responsible for all the life functions it makes itself felt throughout the entire body, and it exerts its influence on all the organs and tissues. The mind can not be felt, nor does it have any perceptible weight. Indeed it can not be detected at all through the senses. By analogy Anaxagoras concluded that cosmic Mind too could not be composed of any of the substances which we know through the senses, but that its substance is imperceptible. Because it could not be perceived, like the basic building blocks of matter, its existence and characteristics too could be deduced from observable effects only by means of theoretical arguments.

For Anaxagoras all the perceptible objects in the world are regulated in every detail by Mind. In order to exert total control Mind must perceive, recognize, and constantly observe and survey all the matter, all the molecules that exist. Hence Mind must possess the faculty of perception and be able to interact with matter in order to govern its behavior.

Anaxagoras' analogy between cosmic Mind and the mind of an individual living being was thoroughgoing. The mind of an individual is not perceptible; it interacts with the matter of which the body is composed, governing the motion of the organs, and perceiving and knowing the information registered by the different parts of the body; and, according to Anax-

agoras, who extended the range of activities governed by the mind considerably beyond the range generally attributed to it, the conscious mind regulates and controls all the activities and changes in which all parts of the body participate. So too, by analogy with the individual functioning organism, the cosmic Mind in the universe is imperceptible; it interacts with the matter of which the world is made up, governing the motion of all objects, and perceiving and knowing all the physical changes occurring in different parts of the world; and it regulates and controls all the activities and changes in which all things take part. The fundamental question that Anaxagoras had to answer in the case of cosmic Mind was the same question that must be answered by all those who attempt to explain the workings of the individual mind: How can something perceive, when it itself is not perceptible? How can something interact with matter and control it, when it itself has none of the characteristics of material things?

Anaxagoras turned to the study of how the mind perceives in living organisms, in order to learn by analogy the way cosmic Mind perceives. And in order to understand how the mind in living organisms perceives material things, he studied first the mechanisms by which sensory organs, themselves material, register the stimuli they receive from other material objects in the external world around them. We are therefore obliged to digress in order to consider Anaxagoras' theory of sensory perception in animals.

According to Anaxagoras, perception is a physical interaction between the sense organ and the object sensed, an interaction between the matter that makes up the sense organ and the matter that makes up the object perceived. The interaction gives rise to an irritation or slight prickling sensation in the living organism. The interaction that takes place is thus one in which the object sensed affects, or changes the state of, the sense organ. Starting with this realization, Anaxagoras set about to study the conditions under which one body can cause a physical change in another.

Anaxagoras took as his starting point the generally observed fact that two bodies having exactly the same properties in all

respects do not affect one another when they are brought into contact. For example, when two liquids having the same taste, color, density, etc. are mixed, the resulting liquid is no different from either of them in its properties and composition; when two bodies having the same temperature are in thermal contact, no temperature change occurs in either body, nor do any of the physical properties dependent on temperature undergo change; in a similar manner two notes of the same pitch sounded simultaneously can not be distinguished from each other. Only if the bodies which are involved in an interaction are *different* in at least some of their properties will a noticeable change occur: thermal effects will be observed when a warmer body is brought into contact with a cooler one; a fluid mixture will be different from its components when the components themselves are somehow different from each other; sounds will be distinguishable when they are of different pitch. Anaxagoras summarized the results of these common everyday observations in a general law of physics, that *interactions which lead to observable physical change can take place only between bodies whose states differ in some way.*

Anaxagoras went on to apply this principle to the interactions which he thought constitute perception. We know that Anaxagoras wrote in some detail about the mechanism by which each of the senses functions. Unfortunately there survives only a fragmentary description of this part of Anaxagoras' work, so that we are able to reconstruct only a small fraction of his theory of sensory perception.

Anaxagoras' statement that everything contains within it some molecules of everything else applied of course to the sense organs as well. They too contain all kinds of matter possessing all of the qualities that exist. Thus some properties of the sense organs are usually different from those of any particular object sensed. This difference makes perception possible, since the interaction which gives rise to sensation occurs whenever properties of the perceived object are different from properties of the sense organ with which the object comes into contact. In this way, for example, we become aware of heat when an object in which hot molecules predominate comes into contact with

our organ of touch, provided only that the *exact* same proportion of hot to cold particles is not present in both the object and the sense organ (a relatively unlikely coincidence, given the endless variety of proportions and temperatures which can exist). Similarly, hard objects are felt if the organ of touch yields to them, and soft bodies will be perceived if the organ of touch is harder than they. Anaxagoras was able to explain the functioning of the organs of touch generally, along these simple lines.

We do not know how Anaxagoras explained the mechanism of the sense of smell, beyond the simple fact that he noted that we smell when we inhale. In regard to the sense of hearing Anaxagoras held that sound is a disturbance transmitted by air, which is heard when it is carried into the sinuses of the head and reverberates there. However, the exact mechanism Anaxagoras postulated for the perception of sound is lost to us.

Of Anaxagoras' account of the sense of taste little more remains than what we know of the sense of touch. The organs of taste perceive a certain taste as a result of the interaction between matter taken into the mouth and matter of a different flavor residing in the mouth. Thus when something sweet is eaten it is perceived by the particles of bitter matter in the taste organs of the mouth, and when something salty is taken in it is perceived by particles of bland matter. (We have no reason to believe that different tastes were thought by Anaxagoras to be localized in different parts of the mouth. His was not, as far as we know, a rudimentary theory of taste buds.) Again the presence of all qualities in the matter which makes up the organs of the mouth enables us to perceive all the different kinds of tastes.

A fairly complete account of Anaxagoras' ingenious theory of vision has survived. Anaxagoras noticed, by means of what must have been very careful observation, that we see exactly those images which are reflected in the pupil of the eye—no less and no more. Today we have no difficulty in understanding this, because we know that light stimuli are registered on the retina in the interior of the eye. Since the retina can only record light

that enters the eye, and since the only opening into the eye is the transparent pupil, it is clear that we see only that light which passes through the pupil. Since we also know that when light passes through a transparent object some proportion of the light is always reflected, it comes as no surprise to us that precisely those images which appear on the retina are reflected in the pupil, through which their light passes on the way to the retina. For Anaxagoras, who did not know the role the interior of the eye plays in vision, and ascribed the primary role to the surface of the eye—where the eye and the outside world come into direct contact—it was no small feat to discover that only the image reflected in the pupil, and not any part of the image reflected in the iris or in the white of the eye, is actually seen. From this remarkably precise observation Anaxagoras concluded that only the pupil plays a role in vision, and that the mechanism of visual perception is *the reflection of light in the pupil*.

The pupil of the eye is black. Therefore, according to Anaxagoras' general theory of interactions, all objects which are *not* black will be reflected in the pupil and consequently be seen. In fact black objects can never be seen at all unless they are illuminated by some external source of light. Furthermore, the brighter the objects the sharper the contrast with the pupil, and hence the more distinctly they are seen. This explains why objects hidden in shadows or obscured by hazes are seen less clearly than objects bathed in sunlight or otherwise adequately illuminated. For the same reason the ability to discern objects decreases as night approaches, and it disappears altogether in total darkness: the black of night is the same color as the black of the pupil, so that there is no difference at all between the color of the organ of sight and the color of the surroundings, and no interaction can take place. Another apparent point of support for Anaxagoras' theory is the observation that many animals noted for their keen nocturnal vision have bright eyes.

In general for all the sense organs, the larger the animal, the larger the organ. This means that the region over which the sensory interaction takes place is proportional in size to the size

of the animal. In this connection we have a cryptic statement of Anaxagoras' to the effect that large animals perceive more than do small animals. We do not know whether this statement means that large animals can perceive larger objects, that is, that they gather stimuli from a broader field of perception; or that they can perceive objects which lie at a greater distance, that is, that the depth of their field of perception is greater; or that they can perceive finer details, that is, that their perception is more sensitive; or whether it means all or some or none of these things.

All the mechanisms of sensation discussed above are specific instances of the general law governing the way in which perception occurs: in all cases of perception, in all the processes which lead to the acquirement of knowledge, the mechanism of sensation must be an interaction between things having different properties. This then is the universal principle that is suggested by a study of sense perception in living beings. It is this that Anaxagoras used to describe the nature of Mind.

By definition, cosmic Mind perceives and has knowledge of everything in the universe. Nothing is hidden from it; all processes are controlled by it, and it must comprehend them all. Its activity pervades everything, since everything in the universe is governed by natural law. Now according to Anaxagoras' theory of perception these properties of Mind could lead to only one conclusion about the nature of Mind: Mind must be different from *everything* in the perceptible universe; in particular, Mind must be different from *all* matter. Nor can Mind have any of matter's properties; it can not have weight, hardness, moisture, elasticity, color, temperature, or *any* of the qualities which apply to matter. For if Mind was like any substance or had any of these material qualities, it would be unable to perceive, know, and comprehend that substance or quality which it resembled. Mind therefore, which pervades all the matter in the universe, is entirely free from the admixture of any of the matter in the universe. Mind is, in short, the opposite of matter: it is incorporeal.

Because of the confusion that can easily arise in this matter, it is worth noting explicitly that there are two basic kinds of

incorporeality. There is the incorporeality of color, temperature, number, shape, extension, character, and all such *predicates*. These things are incorporeal by definition, since they are by definition *attributes* of objects and are on a different conceptual level and in a different logical category from matter. This however is *not* the incorporeality of Mind, because Mind is not an attribute or property of matter. Rather, Mind is something which acts on and affects matter, and which is itself qualified by predicates. Mind's incorporeality is of the second kind: the incorporeality of real substantial entities whose presence is felt by matter and whose force is manifest in matter; the incorporeality of things which are themselves qualified by a variety of properties, but which can not be directly perceived, and have none of the properties commonly associated with perceptible matter. This second kind of incorporeality is the kind commonly associated with the soul. It is the incorporeality usually intended by the theologian when he speaks of an incorporeal God. It is the incorporeality associated with the forces used by physicists in their description of dynamical laws. It is the incorporeality which has always been attacked by those who would consistently eliminate from their formulations all entities which are not directly perceptible. This is the incorporeality of Mind, which involved the conception of some kind of real, effective, pervading thing which is totally different from anything material.

Anaxagoras was the first Greek thinker to introduce into his system of thought an incorporeal substantial entity. He was the first to conceive the possibility of the existence of such an incorporeal substance, and his conception had a profound influence on succeeding generations of scientists and philosophers even to the present day.

Chapter Six

THE CREATION OF THE WORLD

The general features of Anaxagoras' cosmogony were again drawn by analogy from everyday experience. Whenever a structured object is formed, whether by artificial or natural means, the process involves the arrangement of disorganized pieces of matter into an ordered whole. At first there is no sign of the emerging entity in the disordered parts, and none of its distinctive features can be seen in them. Then, at some time which marks the beginning of the object's appearance, some slight gross order comes to view; then more and more structure appears, until finally the end-product stands before us, complete in all its details. Anaxagoras drew an analogy between innumerable particular instances of this type, and cosmic occurrences which involve the entire universe and all that is in it, and constructed his theory of the creation of the world by generalizing from specific cases to the cosmic event in which the world came to be.

According to Anaxagoras, all the matter in the universe originally lay in a jumbled heap for endless aeons of time, completely unformed, motionless, and unchanging. A mass of infinitesimal particles indiscriminately mixed together, containing all the varieties of matter which we see around us (which always have existed and always will exist), lay dormant and static, undergoing no process, showing no order, and revealing no design. For an infinite eternity, from the beginning of time, the infinite universe was motionless. No single kind of matter predominated in, or bestowed its particular characteristics on, the mixture; the mixture was completely disordered and all the various kinds of matter with all their qualities were strewn about in it in random chaos. Thus the universal mixture had no dis-

tinguishing property or special aspect, since no single one of the components it contained was able to come to view.

Not only were all parts of the mixture stationary relative to each other, but the mixture as a whole did not undergo translational motion either. This is because the mixture was infinitely large, there being always more beyond any point, and there was no place beyond it into which it could have moved.

Mind, the source of all motion, change, and order, was inactive during this entire span of time. It had not yet begun its work. In this period the dynamic laws of nature had not yet taken hold of the physical universe; this period of dormancy knew no change of state. We do not know how, or whether, Anaxagoras got himself out of the impossible position he had taken in this regard: for by carrying out his generalization from particulars to the universe, he had ended with the paradox that Mind, and hence the law that governs change, being real and eternal, always existed, but its effects were nowhere felt during the infinite span of time before the creation.

At a certain moment however, according to Anaxagoras, Mind began to function, and by instituting motion began to impose order on the chaotic matter which filled the universe. Anaxagoras described in terms of familiar natural laws the series of mechanical processes by which Mind effected this fashioning of the world. There was nothing supernatural about these processes; they were the same as those going on in the world today.

The first stage of the creation comprised the massive rearrangement of matter necessary to give rise to the gross structure of the universe as Anaxagoras saw it. The first step was to separate heavier from lighter matter, leaving a core of earthly and liquid substances surrounded by air and other gases and vapors. What common physical process could cause a random mixture of different kinds of matter to be separated into a central core of higher density and a surrounding medium of lower density?

Anaxagoras found the answer in the observation that eddying liquids or gases draw to their center objects denser than the medium. Ships are sucked into the heart of great whirlpools at

sea; dust is pulled to the center of vortices in windstorms; houses and trees are drawn into the eye of cyclones. Whenever a fluid is set into rotation a rearrangement of the matter within it takes place, and denser objects are drawn towards the center of the whirl.

Anaxagoras identified the natural physical process through which Mind acted and effected the first stage of the creation with the separation of heavier from lighter objects caused by whirling motion. According to him, Mind began its work by churning the universal mixture, and so brought most of the dense matter in the universe to the center, and left air and other lighter material predominating outside. This was only a coarse separation; there remained molecules of heavy matter all throughout the outer regions of the universe and molecules of light matter all throughout the earth, because there are some molecules of all kinds in all things. So the universe took on for Anaxagoras the aspect it seems to have at first sight: a concentration of dense substances around the center of the earth and a distribution of light substances around the earth and out to infinity; and Anaxagoras believed that the process which caused the originally homogeneous mixture to take on this aspect was the churning motion initiated by Mind as the first step in the creation.

When the gross structure of the universe had been established, the churning motion died out. The matter in the universe reached a state of over-all stability, and large masses of different substances were no longer continually churned about. It is not clear whether or not Anaxagoras tried to explain the rotation of the heavenly bodies as the one remaining vestige of the original churning motion. At any rate the heavenly bodies are the only large bodies which still participate in rotational motion on a cosmic scale, while in Anaxagoras' view the original churning, which had once involved all the matter in the universe, had long since ceased.

We know that Anaxagoras dealt somewhere in his theory, probably in the description of the cosmogony, with certain angles of inclination. What these were we have no way of ascertaining. They may well have been related to the angle of in-

clination of the celestial equator to the surface of the earth, or to the angle of inclination of the plane of the ecliptic to the surface of the earth.

The workings of Mind were also responsible for every detail of the present order of things. For according to Anaxagoras the formation of each of the particular distinct objects in the world, and the organization of every specific sub-system in the universe, were all directly traceable to the action of Mind as manifested in some natural process. Through appropriate and usually different mechanisms in each instance, Mind brought about the formation of the sum total of all things in the universe and set everything in order. We do not know how Mind succeeded in producing the fine structure of the universe; but however Mind completed its work of creation, when it was done, the universe as we know it stood entire. The flat earth lay at rest at the center, its large flat expanse supported by the mass of air beneath it, much as a large flat kite is supported as it floats gently in the air.⁸ On the earth geological formations were created, vegetation arose, animals came to be, and finally civilizations emerged, until at last the earth acquired all its present features. The creation was over. Mind, which had brought it about, had now only to keep it going according to natural law.

Chapter Seven

SPECIFIC PHYSICAL THEORIES

In the following chapters we shall present the few surviving remnants of Anaxagoras' specific theories, which were meant to serve as scientific explanations for the detailed behavior of material objects in the world around us.

One of the first things the student of physics is called upon to explain is how things move in general and how free bodies behave in particular. It is readily seen that in the absence of any obvious external force of constraint, there are two kinds of motion which normally occur in everyday life: rectilinear motion in the up-down direction and rotational motion. In both cases the way bodies move depends on their density, so that objects of higher and lower densities can be distinguished from one another by their behavior; in the up-down motion occurring in nature, bodies released at rest and permitted to move freely tend either towards the earth if they are denser than air or away from the earth if they are lighter than air. In circular motion of the kind observed in whirlpools heavy bodies are distinguished from light ones by the fact that they move towards the center while the lighter ones move to the periphery.

We have seen in the previous chapter how Anaxagoras made use of the behavior of fluid vortices to construct theories which pertained to the universe as a whole. In the case of vertical linear motion too it was a simple step for Anaxagoras to generalize from everyday observations to the law that *all* heavy bodies, heavier than air, not subject to constraint will fall downward. An immediate consequence of this law, one which has plagued people from earliest times, is that the entire earth should be falling through space! Since it obviously does not fall, but remains instead quite motionless—as anyone can see—Anaxagoras had to seek some physical mechanism which would

allow a body that would normally fall to remain suspended. Once again he was able to call on experiences familiar to all; everyone has seen leaves, pieces of paper, and birds with outspread wings hovering in mid-air, supported by the resistance of the air beneath them. Furthermore, it is well known that the larger the surface area of a body the greater ease with which it remains aloft without falling. The great force which so insubstantial a thing as air can muster against a heavy object can easily be seen on windy days, when air alone is able to impel ships and even to destroy trees and buildings. Anaxagoras reasoned that the earth, being flat and immense in size, could with little difficulty be supported by the air beneath it. He pictured the earth as a great flat expanse floating motionless on a cushion of air.

The tendency of light objects to rise and heavy ones to fall indicated to Anaxagoras the presence of a fundamental up-down asymmetry in the universe at the present time. On the other hand in recounting the creation of the world, he had invoked a different dynamical process involving circular motion, which served to collect heavy matter at the center where the earth was formed and to disperse light matter all around to the farthest reaches of the universe. Indeed Anaxagoras could not have used the natural rectilinear motion of heavy and light matter in his cosmogony, since such motion simply separates heavy from light in an up-down direction. Had he made use of vertical rather than circular motion, he would have arrived at a theory in which all the heavy matter in the universe fell downward, and all the light matter rose upward; so that there would have been no way for dense matter to come together to form a cohesive solid mass of earth, since all dense matter would be falling and there would be nothing tending to bring it together. Anaxagoras was forced therefore to introduce a churning motion during the creation of the world.

However, as we have seen above, as soon as the creation was complete, the general rotational motion died out. In place of it there then appeared the vertical linear motion which has since been the natural motion of free bodies when released from constraint. Still, some vestiges of the spherical symmetry which

held sway during the creation remained even after up-down asymmetry had been introduced—a feature which caused no little embarrassment to Anaxagoras' theory in its final form. Thus, the original churning motion brought heavy substances to the center of the infinite universe and caused these to be surrounded on all sides by lighter gaseous matter, even at the present time, though this state of affairs is not at all consonant with the vertical asymmetry which causes light matter to rise and heavy matter to sink to the very bottom of the universe. The inherent contradiction between these two pictures, the result of the very different dynamical properties of free fall and of rotational motion, does not seem to have occurred to Anaxagoras. He apparently saw no problem in stating at one and the same time that gases always tend to rise above solid matter and that there is air all around the earth, even underneath it.

Since Anaxagoras considered the air beneath the earth capable of supporting the earth, he was clearly aware that a gas has the ability to exert considerable pressure even when it is at rest and not only when it is moving in violent gusts. Anaxagoras was one of the first to demonstrate experimentally that air, which seems so insubstantial—the same air which is so easily riven and which usually scarcely impedes a body moving through it—can in fact resist a large impressed force. Anaxagoras showed this to be true in public demonstrations, of which reliable reports have survived. In one experiment he inflated a wine skin and then twisted the neck of the skin until the compressed air rendered its pliable container firm and hard. He then showed that under these conditions the skin would resist a considerable force exerted against it, due to the counterforce exerted by the air trapped inside. Two other experiments were performed with the aid of a water clock, or *clepsydra*, a simple instrument designed to measure time. The water clock was a container with small holes in the bottom and with an opening at the top fitted with a stopper. The device was operated by filling the container to a prescribed level while the holes in the bottom were covered. As long as the top was stoppered the water would not escape through the holes in the bottom, provided the clock was held in a vertical position. When the

stopper was removed the water streamed out, and intervals of time could then be measured in terms of the volume of water that had flowed out. By adjusting the size and number of the holes or the size of the container, clocks could be manufactured which conveniently measured any desired length of time. These clocks were commonly used, for example, in courtrooms to time speakers; they were well-known devices from ancient times on.

The two demonstrations Anaxagoras performed with such water clocks were the following. In the first he took an empty water clock and stopped its open end. After doing this, he plunged it vertically into water and showed that no water entered the holes at the bottom. He correctly interpreted this result to mean that the air inside the water clock, because it was trapped in a closed container, exerted sufficient pressure to keep the water from entering. In the second experiment he investigated the behavior of a filled water clock. First he showed a filled water clock closed with a stopper, with no water flowing from it. Here, he explained the fact that no water flowed out as being due again to the force of air, this time of the air pressing up against the water through the holes in the bottom of the water clock. Then he removed the stopper and allowed the water to flow. Since the only difference between the two situations was the absence of the stopper in the second case, Anaxagoras concluded that the water could leave the container because air was able to flow around from the bottom to the top to make room for the escaping water. With such experiments, Anaxagoras attempted to convince his audience that the air around them was indeed capable of exerting pressure.

Anaxagoras did not ascribe any of the effects observed in these experiments—or anywhere else, as far as we know—to *atmospheric* pressure. He certainly did not envision the blanket of air around the earth as having any weight, for air was nowhere observed to fall downward, or to crush anything under its weight. What Anaxagoras meant by the force exerted by air was an elastic resistance of air, the kind of resistance offered by virtually every material medium subjected to compression. This elastic resistance is, to be sure, the source of the resistance he saw exerted by *trapped* air in the course of his demonstrations.

Anaxagoras however believed the same resistance on the part of free air to be responsible for keeping water inside a stoppered clepsydra, though unenclosed air has nowhere near enough resistance to justify such an assumption. In fact, such a high degree of elastic resistance for air not enclosed in a container would be entirely incompatible with the observation that bodies pass through air for the most part with great ease.

Anaxagoras also used air's resistance to compression to explain why leaves and other light flat objects float in air, and here his explanation was correct. This is the property of air which enabled him to make plausible his theory that the earth floats on the air beneath it like a huge leaf. From the experiment he performed with a filled water clock Anaxagoras thought he could conclude that the only way the earth could sink to a lower position would be for some air to creep out and around from under the earth, as it flows around leaves, allowing them to sink slowly downward. However, if the earth is sufficiently large such a process can not take place, since it requires large subterranean currents of air for which there is no evidence at all. The great size and flat shape of the earth, together with the elastic properties of air, therefore assure the earth its stability. Once again we see before us an example of how Anaxagoras extrapolated the observed properties of terrestrial systems to cosmic dimensions.

The fact that Anaxagoras illustrated his scientific lectures with demonstrations is in itself significant. It shows that in Anaxagoras' day it was not unusual to supplement direct observation with active experimentation and that the experimental branch of natural philosophy, which was gradually to match and outstrip the purely observational branch, was already an acknowledged partner of the theoretical branch as far back as the time when rigorous scientific method was being born.

By combining theory and observation Anaxagoras concluded also that there is no such thing as a void, i.e. no such thing as absolute emptiness. Logically this followed from the Law of Contradiction; for it is impossible for something which does not exist in any way, and which has none of the characteristic

properties of existing things, to exist. Observationally it was based on the fact that all of space around us *is* filled with something. In addition, Anaxagoras' experiments with wine skins and clepsydras served also to demonstrate that even what appeared to be totally empty space was actually filled with air, which turns out to be a very substantial thing indeed. Moreover, suction phenomena provided additional proof that some matter always rushes in to fill a space which is in the process of being evacuated. Here too Anaxagoras generalized his experience into a fundamental law of nature, which stated that the whole universe is a material continuum filled everywhere with the same kinds of matter and containing no gaps of absolute emptiness.

It was easy for him to explain how objects are able to move from place to place even though all of space is filled with matter. For liquids, which certainly appear to be continua, obviously allow of motion, whether it be the motion of one part of the liquid sliding over another or the motion of a solid object cutting through successive parts of the liquid. So too all matter manages to move by displacing the surrounding medium; and the motion proceeds with more or less difficulty, depending on the resistance offered by the medium.

Anaxagoras took as a basic law of physics the familiar observation that, in fluids, warm matter tends to rise and cold matter to descend, thus making use of the notion of heat convection which is one of the most important means of explaining the transfer of heat from one place to another. Anaxagoras realized that the mechanism of heat convection is operative on a large scale as well as in specific small-scale instances of heat transfer, taking it to be one of the main factors responsible for meteorological phenomena.⁹

Anaxagoras seems to have understood what it is that causes convection currents to flow. He was aware that a hot substance is less dense than a cold one. Knowing this, he had only to invoke the gravitational properties of matter in order to account for the fact that hot matter, being less dense, rises above cold matter, which in turn descends to take its place. Though we

have no evidence that Anaxagoras actually took this step in his thinking, it is not unlikely that he understood the reason for heat convection.

Anaxagoras did speak of a coarse separation of different kinds of matter according to density during the creation of the world, as a result of which the lightest—and hence, for the most part, predominantly hot—substances occupied the region of space farthest removed from the earth. What actually occurs in nature is that the temperature of the air gets *lower* as one proceeds to higher and higher altitudes but according to Anaxagoras this was only a local fluctuation in the over-all picture, because he held that as one goes even farther from the earth into the regions of outer space the temperature rises to that of flaming-hot aether. In order to impress his readers with this “fact,” Anaxagoras gave an etymological explanation, which would be in accord with his picture, for the name “*aithēr*” (“aether”) by which the outermost reaches of the universe were popularly known in his day. He pointed out that this commonly used name could easily and appropriately be derived from the verb *aithō*, which means “to be burning hot.”

Anaxagoras also dealt with certain aspects of optics. More than any other early physicist he is associated with the conviction that light travels in absolutely straight lines, believing in the completely rectilinear propagation of light even over cosmic distances.¹⁰ His theory concerning the reflectivity of different surfaces, an offshoot of his general theory of interactions, stated that the ability of a given mirror to reflect light depends on the contrast between the color of the incident light and the color of the reflecting surface, and that the greater the contrast between these two colors the more strongly and clearly will the incident light be reflected; whereas incident light of a color which is the same as the color of the mirror on which it falls will hardly be reflected at all.¹¹ His color theory, to which his theory of reflectivity was related, requires further comment.

Anaxagoras seems to have shared with most physicists of his time, as well as those of succeeding generations up to modern times, the theory that all colors lie on a continuum between two extremes represented by black and white. It is well known

that all colors merge into blackness as they become darker in shade and that they approach closer and closer to whiteness as they become lighter in shade; so that in fact all colors become more and more similar to each other as their shades get nearer and nearer the two extremes. This was taken to indicate that each hue lies on a one-dimensional continuum between black and white; and a graphic representation of this color theory would show each color lying on a different curve joining the same two endpoints of black and white. Anaxagoras could consider black and white as the two basic primary colors, since in a sense all other colors lie between these extremes—just as in the case of temperature he took absolute hotness and absolute coldness to be the two primary degrees of heat. The only difference between color and other qualities is that in the case of color there are many different paths between the two extremes, corresponding to the various hues. This means that a certain proportion of black and white molecules does not uniquely define a *hue*, though it does define a *shade*. How Anaxagoras accounted for different hues, whether by assuming different *kinds* of black and white extremes for each hue, or by some other method, has not come down to us.

As applied to Anaxagoras' theory of reflectivity, his theory of color implied two things. First it implied that a mirror of a given *hue* will reflect light of a hue different from the mirror's, which is therefore able to interact somehow with the mirror's surface, better than it will reflect a hue close to its own. For example, a mirror of polished red bronze will reflect a red bronze object more poorly than any other kind, in the sense that the image of the red bronze object will be harder to make out. Second, Anaxagoras' theory of reflectivity implied that a mirror of a given *shade* will reflect other shades (of all hues) more strongly and clearly than it will reflect a shade like its own. For example, a mirror whose surface is light in color will reflect dark shades of all hues better than it will reflect light shades of these hues.

There remains only a tantalizing remnant of a theory concerning the nature of sound and thermal noise. Anaxagoras held that we can hear better at night than by day because

during the day the heat of the sun causes the air to crackle and therefore renders coherent sound less distinct. We know nothing of the reasoning which led Anaxagoras to this statement. He certainly thought that the sound we hear is a disturbance propagated through air, and in Anaxagoras' explanation of lowered audibility by day we find him relating heat to sound. It is impossible to tell whether this explanation reflects a genuine theory of thermal noise in which the noise is attributed to the random motion, induced by heat, of parts of the air, or of fine particles suspended in the air; or whether it derived from the simple analogy between the crackling emitted when things are heated by a fire and the assumed noise emitted by air when it is heated by the sun. Either way the explanation is only partially correct. There does indeed exist a background of thermal noise due to the sun during the day, but this noise is by no means sufficiently intense to produce a noticeable effect on the clarity with which sound is transmitted and heard. Much more important is the higher external noise level which exists due to the generally greater amount of noisy activity going on during the day.

Chapter Eight

ASTRONOMY

Nowhere is Anaxagoras' belief in the unity of nature more evident than in his astronomical theories. He was convinced that the same kinds of matter are found in all parts of the universe, that they all behave according to the same physical laws regardless of where they are located, and that he was justified in applying the results of his terrestrial investigations to the explanation of celestial phenomena as well. It was therefore a cornerstone of his thinking that, if at all possible, no astronomical theory should involve any special new substances or mechanisms not used in the earthbound part of his system. This aspect of his scientific thought was probably the best known of all to scientists who knew his name throughout the ages.

This demand for unity in nature led Anaxagoras to say that the sun is a blazing object similar to the earth in its composition. Specifically, he said the sun is a red-hot mass of metallic ore—perhaps because it glows much as does molten ore in a furnace. We do not know how he explained the fact that such a heavy body stays up in the heavens and does not fall. He may have viewed the daily rotation of the sun and the other heavenly bodies as vestiges of the churning motion that prevailed during the creation of the world.

Anaxagoras' conception of the nature of the moon was somewhat different. He thought of the moon too as being much like the earth in its composition, but held that it does *not* give off its own light but shines instead by the reflected light of the sun. On the basis of this view he would have been able to give a fairly complete explanation for the phases and eclipses of the moon, provided he assumed also that the moon was nearer the earth than the sun. Unfortunately we do not know if he

made this assumption nor have we any reliable reports from which we could conclude that he constructed a theory of lunar phases or eclipses. All we know is that he explained the faint image of the full outline of the moon which is seen soon after the new moon, the dimly illuminated disc which is half encircled by the bright thin crescent of the nascent moon, and which is therefore popularly called "the old moon in the new moon's arms," as being due to the presence of a small amount of residual sunlight left over from the previous month.

Sunlight also played a role in Anaxagoras' explanation of one of the most striking phenomena of the night sky, the Milky Way. The band of white light which stretches across the sky and changes position relative to the horizon from season to season long baffled people. The name it is commonly given derives from a myth which told that it was a stream of milk; but other accounts were also offered. Anaxagoras' explanation of the Milky Way was unique among these in that it combined a number of fundamental principles of physics: the principle of economy in nature, the laws of optics, and the principle of spherical symmetry, or isotropy, of the universe relative to the earth taken as the center. We have seen that Anaxagoras held that there is an isotropic distribution of matter outside the earth, especially in the more distant outer regions.¹² This spherical symmetry he held to be a fundamental property of nature. In accordance with it, he concluded that the distribution of stars in the sky is completely isotropic, and that all parts of the heavens have the same density of stars.

To avoid introducing new *ad hoc* hypotheses, Anaxagoras denied that the Milky Way is different in any way from other heavenly bodies, but maintained that it consists of stars just like the rest of the stars that shine in the sky. However, since the band of the Milky Way is far brighter than its surroundings, the density of the stars in it must be much greater than the density of stars in the rest of the sky, in contrast with the isotropy just demanded above.

The only way for Anaxagoras to resolve this apparent conflict between the requirements of the law of symmetry in nature and those of the principle of economy was to find a mechanism

which would explain why one part of the sky looks brighter than another though all parts contain the same number of stars. The explanation clearly lay in the realm of optics, and there Anaxagoras found it. During the day no stars are seen in the sky though everybody knows that they are present. The reason they are not seen by day is that the sun outshines them. Anaxagoras could thus explain any lack of isotropy in the observed distribution of stars as due to the presence of a fairly strong source of light, which outshines some stars and lets others appear.

Anaxagoras believed that the same sun that masks the light of the stars during the day is responsible for the apparent unevenness of their distribution at night. The sun under the earth at night shines on most of the stars in the night sky, though more faintly than by day. The reason the sun's light does not have sufficient intensity to hide all the stars at night as it does during the day is that at night the sun is between the earth, and hence so much farther away from the stars above. Therefore, the bright stars remain visible and only the dim ones are hidden from view. The part of the heavens on which absolutely no sunlight falls is the part which lies in the geometrical shadow of the earth. There *all* the stars are visible, the weak ones as well as the bright ones. According to Anaxagoras the stars which lie in the band defined by the shadow of the earth form the band of the Milky Way, and the density of stars observed in the Milky Way is, by the principle of isotropy, the true density of stars throughout the heavens.

Anaxagoras' theory of the Milky Way provides us with a large-scale example of his conviction that light always travels in straight lines. His explanation required him to believe in the rectilinear propagation of light even on a cosmic scale. Otherwise it would have been impossible for him to assume that a well-defined shadow of the earth extends across the heavens.

Anaxagoras also accounted for comets by means of familiar entities and mechanisms. Instead of introducing some new kind of celestial body into his theory, he chose to explain the appearance of comets in terms of other heavenly bodies well-known to everybody.

To the naked eye a comet looks like an extremely small streak of light in the night sky, like nothing more than a slightly extended source of light. It looks very much the way two distant point sources of light look if they are so close to each other that they cannot be resolved by the eye into two separate images. Now planets change their positions relative to the fixed stars and relative to one another. In particular, they are capable of coming so close together in the sky that the eye can no longer distinguish them, but sees instead a small bright streak looking like an extended source of light. Because of this Anaxagoras assumed that what we call a comet is actually a conjunction of two or more planets. In this way he rendered a completely obscure phenomenon intelligible in terms of familiar things.

Although we possess only these few remnants of Anaxagoras' astronomical theories, all of them show clearly the way in which he approached the subject: in each instance he strove to reduce the amazing and the obscure to the familiar, the natural, and the commonplace.

Chapter Nine

EARTH SCIENCES

It is not unusual for hail to fall in the summer as well as in the winter. This has always been a source of great puzzlement, because one would expect that water cannot freeze out of doors in warm weather. A theory of hail-formation must show how it can. Anaxagoras began from the observation that the higher up you go the colder it gets. From this he deduced that water could freeze at very high altitudes even in the summer. All he had to explain was how water-laden clouds got to altitudes high enough to enable them to freeze.

Anaxagoras knew that heat causes things to rise and creates convection currents in the atmosphere.¹³ It was therefore quite natural for him to assume that the heat of a summer day can drive clouds up to extremely high altitudes, whether by heating the clouds themselves and making them less dense and thus able to rise, or by causing the clouds to be pushed up by rising air currents. Once they reached sufficiently high altitudes, the clouds would presumably find themselves in surroundings cold enough to cause water to freeze. As a result, the water in the clouds would freeze and fall as hailstones back to earth. According to this explanation, it would not be surprising for hailstorms to occur even on the very hottest days; for the main effect of the intense heat might well be to drive clouds upwards more rapidly and so to give rise to a swifter and more effective process of condensation.

Anaxagoras explained the drop in temperature with altitude as due to the progressive decrease with height in the intensity of sunlight reflected from the surface of the earth. Apparently he assumed that together the directly incident sunlight and the sunlight reflected from the earth's surface are responsible for the temperature of the regions of space in which they fell.

Since it was natural to suppose that sunlight reflected from an uneven surface would spread out equally in all directions, he concluded that its intensity must drop as one got farther from the earth. Since, then, the reflected component of sunlight diminishes as one goes higher, the temperature must diminish as well. This decrease eventually stops and is replaced by a progressive increase in temperature as the outer regions of burning-hot aether are approached; but the reversal occurs beyond altitudes which are meteorologically significant.

According to Anaxagoras, however, aether sometimes enters regions in which weather phenomena occur. For him thunder and lightning were both caused by falling aether. Indeed he thought they resulted from a single event, an insight which in itself was not trivial, or by any means universally shared by his contemporaries and successors. He held that when some aether falls it gets caught in the clouds and burns in the atmosphere with a fiery glow which we see as lightning. Since the clouds contain moisture, this fire is instantly extinguished to the accompaniment of a great, loud, sputtering noise which we hear as thunder. This explanation is in complete agreement with the fact that lightning is always perceived before thunder; for fire must be present before it can be extinguished.

Again we see how unwilling Anaxagoras was to introduce a new substance into his theory. Rather than do so he ascribed the flashes of light he saw in the clouds during thunderstorms to the burning glow of fire which he always identified with the presence of bright, blazing light, whether in a fire, or on the sun, or anywhere else. Lightning was thus for him nothing else than another instance of fire. Moreover, Anaxagoras insisted that the actual circumstances should conform exactly to the observed data, so that whatever the events that constituted thunder and lightning, they had to occur in the order in which they are seen.

The difficulty in this theory is that it involves an unpredictable fall of aether from the distant outer regions, where it is normally found, to the atmosphere. Anaxagoras gave no reason, no physical mechanism, for this striking, abnormal behavior of aether. Aether is the hottest and lightest of all substances, and there-

fore should always tend to rise if left alone. The entire theory of hail formation depends on the natural upwards tendency of hot things. In the case of thunder and lightning we are unexpectedly confronted with a situation in which a piece of aether falls, although not the least cause is given for this erratic behavior, and no indication of the way one might tell when the fall would occur. If however this arbitrary behavior of a hot substance is assumed, the rest of the theory follows naturally.

The hypothesis of falling aether was also used by Anaxagoras to explain the occurrence of earthquakes, together with their attendant phenomena. Earthquakes are frequently accompanied by volcanic disturbances in which flaming gases and burning-hot substances of all kinds are belched forth from the earth and rise upward. The violence of these geological upheavals suggests that they are in some way caused by the build-up of tremendous pressures under the surface of the earth, pressures possibly originating in the hot substances that sometimes burst forth during and after the tremors. Anaxagoras knew pent-up gases are able to exert a considerable force,¹⁴ and also that hot gases tend always to rise. From this he reasoned that earthquakes are caused by quantities of hot aether trapped underground, which try to force a passage upward until they succeed in rending the earth and escaping. As in the case of thunder and lightning, here too Anaxagoras gives us no clue as to why or how the aether falls from its usual place in outer space to the regions under the earth. Here the omission is more glaring than before, since the two physical mechanisms involved in earthquakes are in contradiction; earthquakes are caused by the upward tendency of aether, a tendency which must be temporarily inoperative when aether falls.

Although we are not told how aether gets underground Anaxagoras did explain how it is trapped until it manages to break a path to the upper air. He noticed that the surface of the earth is quite porous and pocked: it is filled with caves, caverns, subterranean vaults, and pits; it is cleft with fissures from which gases are constantly escaping; and even the soil is porous enough to allow water to seep down slowly. Once the hot aether has fallen into one of the cavities in the earth it does

not easily find its way out again because most of the openings to the air above the earth are stopped up with caked mud which has been formed by rains; so that the aether can not rise vertically upward and escape straightaway. Instead it remains trapped until it either finds a way out, or, augmented by additional amounts of fallen aether great enough to exert the pressures required to break out of the enclosure, bursts out and shoots upward in a spectacular display of fireworks and tremors.

We see then that no special subterranean furnaces, no demons, no fires of the underworld were postulated by Anaxagoras in order to account for these terrifying catastrophes. He saw in them the workings of the same burning-hot aether which serves to explain so many phenomena in his theory.

Anaxagoras also concerned himself with one of the major geographical puzzles that has been a source of wonder since the earliest times: the annual overflow of the Nile during the summer. He held that the Nile rises in the summer because it is swelled by the runoff from snows which melt in the spring. He did not specify where these snows were located, and later generations were free to imagine them as far east as the Hindu Kush, as far west as the Straits of Gibraltar, and as far south as the mountains of Ethiopia.

Chapter Ten

BIOLOGY

Anaxagoras' detailed biological theories are not our main concern. Nevertheless we shall briefly discuss those that we know, because they illustrate his method of scientific inquiry, and for the more important reason that in general so few of his theories have survived that any added insight into his method is welcome.

In the complex domain of living things one of the chief ways of determining the function of an organ is by analogy between one animal and another. Anaxagoras drew such an analogy to determine the function of gills in fish. Gills are observed to swing back and forth rhythmically. Their motion immediately suggests that they are playing a role in the function of breathing, except that it seems highly improbable that water contains air for the fish to breathe. For Anaxagoras this posed no problem, in view of his belief that all substances contain hidden in them some molecules of all other substances. Thus according to him water contains molecules of air which can be extracted from it by means of a proper device.

Anaxagoras explained that the gills are organs precisely suited to perform this task, and that they extract air from water by a kind of suction process: each time the fish expels water from its mouth, its gills extract air from the surrounding water, in order to fill the vacuum left by the departing water. The fish then inhales this air into its lungs, and so manages to breathe as do land animals. Land animals are unable to breathe under water by expelling water from their mouths, since they lack the essential organs, the gills.

Anaxagoras was convinced that not only do all animals breathe, but also all plants. He noticed that plants share with animals other characteristics: they too are highly organized

complexes which can impose a degree of organization on their surroundings, as they do for example when they build tissue out of food. Furthermore, plants seem to react to stimuli: they move towards a source of light; they extend their roots towards water; and they frequently open and close their leaves or flowers in response to external excitation. These movements appear very similar to manifestations of desire and will in animals. All the characteristics which seem to be common to plants and animals led Anaxagoras to assume that plants, like animals, contain within them a mind. Nature thus exhibited for him yet another degree of uniformity in that all living organisms without exception carry out all the same life functions and possess Mind.

The unity of the living world in Anaxagoras' theory is so complete that there seems to be no criterion for differentiating between man and the rest of the plant and animal kingdom. In fact Anaxagoras saw little fundamental difference. He said merely that what distinguished man from other living things is one of the most evident physiological distinctions, man's hands. These alone, according to Anaxagoras, enable man to outstrip even the most advanced of the animals in the manipulative skills and technical ability which give him the appearance of wisdom.

Anaxagoras was not however so committed to the concept of unity in nature that he suppressed observational data that seemed to contradict it. Two curious biological theories survive in which he relied on his observations so completely that he felt constrained to introduce peculiar assumptions which applied only to the case at hand. One of these concerns the sexual behavior of crows and ibises, the other concerns the reproduction of the weasel which was the counterpart of today's domestic cat among the ancient Greeks.

Cats are rarely seen in the act of parturition, for when they are about to give birth they go to some remote and hidden spot in order to be free from disturbance. Immediately afterwards they eat the afterbirth and lick the entire area clean; after which they transport their newborn young to their permanent abode. Thus, immediately after delivery, cats with blood-stained

mouths and faces can be seen carrying their very small young from the place where they have given birth. On the basis of such observations Anaxagoras concluded that weasels alone of all animals give birth through the mouth. Anaxagoras also maintained that crows and ibises are unique in that they have sexual intercourse through the mouth. He said this because these birds, though very common, are virtually never seen mounting, while they are frequently seen "kissing" beak to beak. In both instances Anaxagoras slavishly followed observational data, but he did not collect his data carefully enough. One might have hoped that Anaxagoras, faced with two such remarkable exceptions to the general rule in the animal kingdom, would have pursued the problem further and subjected the behavior of these animals to closer and more intensive scrutiny.

Three other isolated statements made by Anaxagoras on biological matters have come down to us without their context and totally unconnected with any observation or theory that we know of: (1) Anaxagoras said that the sex of a child is determined by the father alone. If the sperm issues from the right testis it develops in the right side of the womb, and a male child is born, whereas if the sperm issues from the left testis it develops in the left side of womb, and a female child is born. (2) He held that bile causes acute diseases when it overflows the gall bladder and spatters on the internal organs. (3) He also held that the seeds of plants require sunlight in order to be able to sprout and that it is therefore necessary for them to be wafted through the air on their way to the ground so that they may be exposed to the sun.

Compared with his physical theories, Anaxagoras' biological theories for the most part were not preserved in any detail, or within any general framework. But he was not primarily a biologist and clearly did not give the attention to biological investigations that he gave to physical and astronomical ones.

Epilogue

Anaxagoras' natural philosophy consists of postulates and laws formulated with the aim of explaining the behavior of the physical world rationally. At the root of his system lies careful observation of nature, and where simple observation failed, he sought to devise experiments in order to test his hypotheses and make his conclusions accessible to the public. The data he gleaned from observation and experiment made up the subject matter he explained in his theories.

Anaxagoras did not concern himself primarily with religious or ethical matters, nor did he spend his time speculating about realms not known to man through direct sensory perception. He made no attempt to connect natural phenomena with social justice or moral principles. His world was the world around us, and his *explicanda* were the physical events he perceived. Given these, he tried to set them into a pattern and to relate them to one another by placing them in a logical framework.

Anaxagoras was not satisfied with giving particular explanations to cover each of the different kinds of events that take place. He tried instead to discover unity in nature and so to comprehend as many diverse phenomena as possible within a single law. In his concept of Mind he gave the ultimate expression to this desire for unity and economy in science, although with his theory of Mind he achieved little more than unity of name; but his specific theories too afford many examples of the way in which this desire guided his thought.

Anaxagoras also made use of the concept of symmetry in his theories. The assumption of spherical symmetry in particular allowed him to deduce the nature of one part of the surrounding universe from another. More important yet to Anaxagoras' system of thought was the method of constructing theories by analogy, by which the functioning of the universe as a whole was compared to that of specific entities within it, and the behavior of one specific entity was compared to that of another.

We see then that Anaxagoras began from observation, or, where he felt it necessary, from experiment; that he explained his observations by setting them in a logical framework; that he insisted always that his theories conform to observed data; that he sought a minimum number of explanations to account for all phenomena; and that, to further this sought-for economy of thought, he used the concept of symmetry and the method of analogy as well. Most of the elements of what we today call scientific method were thus to be found in the work of this man whom later generations rightly acclaimed to be the first to speak "like a sober man" after "the stammerers who preceded him."¹⁵

Notes

1. We have accepted the chronology given by Diogenes Laertius in his biography of Anaxagoras. Conflicting chronologies of Anaxagoras' life, none of them reliable, are presented in the ancient sources. We have little confidence in the one we have accepted, but we have adopted it, in the absence of something better, since it seems to us to be a plausible account.

2. See *Webster's Dictionary of Synonyms*, Springfield (Mass.), 1951, p. 546: "Mind . . . denotes a complex of powers of which man is conscious and which includes the perceiving, the remembering, the thinking, and less often, the feeling and willing powers of functions . . . the capacity for understanding and reasoning . . . the exercise of the powers that operate through physical organs (such as the eye, the ear, the brain, the nerves)"

3. See Chapter 10, below.

4. See Chapter 9, below.

5. See *ibid.*

6. See Chapter 6, below.

7. Compare Chapter 3, above.

8. See below, next chapter.

9. See Chapter 9, below.

10. See below, next chapter.
11. Compare Chapter 5, above.
12. Compare Chapter 6, above.
13. See Chapter 7, below.
14. See Chapter 7, below.
15. Aristotle *Metaphysica* 984b15f.

Index

- Aether, 44, 52, 53, 54
Air, 30, 35, 36, 39, 40, 41, 42, 43, 45, 46, 51, 53, 54, 55, 57
Analogy, 24, 27, 28, 34, 42, 46, 54, 59
Animals, 25, 32, 54, 56, 57
Aristotle, 6, 60 note 15
Athens, 2, 3, 4
Atoms, 14, 15
Attributes, 33

Bile, 57
Breathing, 55

Change, 8, 12, 19, 23, 24, 28, 29, 35
Clepsydra, *see* Water clock
Clouds, 51, 52
Color, 44, 45
Comets, 49
Compounds, 14, 16, 18
Conservation of Existing Things, Law of, 8, 9
Conservation of Matter, Law of, 9, 10
Conservation of Place, Law of, 11
Contradiction, Law of, 8, 21, 42
Contrasting qualities, 9
Convection, 43, 51
Crows and Ibises, 56, 57

Density, 35, 38, 43, 44, 48, 49, 51
Diogenes Laertius, 60 note 1
Dissociation and Recombination, 18

Earth, 36, 37, 38, 39, 40, 42, 44, 47, 49, 51, 52, 53, 54
Earthquakes, 53
Eclipses, 48
Ecliptic, 37
Elements, 14, 18
Experimentation, 6, 40, 41, 42, 43, 58, 59
Fish-gills, 55

- Gas, 35, 40, 53
- Hail, 51, 53
- Hands, 56
- Hearing, 30
- Heat, 51, 53
- Heavenly bodies, 36, 48, 49
- Hegesibulus, 2
- Hue, 45
- Incorporeality, 32, 44
- Infinite variety, 7, 12, 26
- Infinitesimals, 12, 13, 16, 18, 20, 21, 34
- Inorganic substance, 15, 16, 17, 19
- Irritation, 28
- Isotropy, 48, 49
- Lampsacus, 3
- Life, 15, 16, 25
- Light, 44, 49, 56
- Logical analysis, 6, 22, 58, 59
- Man, 56
- Matter, 9, 10, 12, 13, 15, 20, 25, 26, 27, 28, 29, 30, 32, 33, 34, 35, 36, 39, 43, 44, 47
- Milky Way, 48, 49
- Mind, 23, 24, 25, 26, 27, 28, 32, 33, 35, 36, 37, 56, 60 note 1
- Molecules, 13, 14, 18, 19, 20, 21, 27, 29, 30, 36, 45, 55
- Moon, 47
- Motion, 23, 24, 25, 26, 27, 28, 32, 33, 35, 36, 37
- Natural Law, 23, 25, 26, 32, 35, 37, 43, 47, 56
- Nile, 54
- Observation, 5, 6, 22, 42, 51, 56, 57, 58, 59
- Optics, 44, 49
- Organic substance, 9, 15, 17, 18
- Pairs of contrasting qualities, 9
- Pericles, 2
- Physical change, 7, 11, 18, 28
- Planets, 50
- Plants, 25, 55, 56
- Plato, 6
- Predicates, 20, 33
- Pressure, 41, 53, 54
- Primary colors, 45
- Properties, 26, 29, 32, 33
- Pupil, 30, 31
- Qualitative change, 11, 19
- Qualities, 9, 10, 12, 13, 19, 20, 21, 29, 30, 32, 45
- Rain, 54
- Reflectivity, 44, 45
- Seeds, 57
- Sex, 56, 57
- Smell, 30
- Snow, 54
- Socrates, 3
- Sound, 30, 45, 46
- Sperm, 57
- Suction, 55
- Sun, 45, 46, 47, 49, 57
- Sunlight, 48, 49, 51, 52, 57
- Stars, 48, 49
- Taste, 30
- Temperature, 44, 51, 52
- Themistocles, 2
- Thermal noise, 45, 46

Thunder and lightning, 52, 53

Touch, 30

Universal mixture, 34, 36

Vacuum, 55

Vision, 31

Void, 42, 43, 55

Volcanoes, 53

Water clock, 40, 41, 42, 43

Weasels, 56, 57

Wineskin, 40, 43

Wisdom, 56

PB 5238-T

Q143.A55 G4 1964
Gershenson, Daniel E.
Anaxagoras and the birth of
scientific method,

MERIMONT COLLEGE
HAMMILL LIBRARY
EAST PA 19004-0001

OCT 15 2001

Mercyhurst College Libraries
Erie, PA 16546



3 3546 00083315 5

Anaxagoras and the Birth of Scientific Method

Daniel E. Gershenson
Daniel A. Greenberg

Of the early investigators of nature whose work is known, Anaxagoras was the first scientist in the sense in which we use the term today. At the root of his system lay careful observation of nature, and where simple observation failed, he sought to devise experiments in order to test his hypotheses and make his conclusions accessible to the public. Most of the elements of what we call scientific method can be found in the work of this man whom later generations rightly acclaimed to be the first to speak "like a sober man" after "the stammerers who preceded him."

Anaxagoras and the Birth of Scientific Method is a study of the theories and methods of one of the greatest minds in the history of science. It presents his ideas as they fit into a unified theory of natural phenomena—a theory characterized by elegance, beauty, and simplicity as well as by unusual incisiveness. Throughout the book, Anaxagoras' work is looked at from the point of view of a scientist surveying the achievements of a distinguished colleague of a past age who was concerned with questions very much alive to

07-DPP-368

